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Intrinsically Irreversible Acoustic Heat Engines
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In a demonstration of an intrinsically irreversible acoustic heat engine, a tube containing a stack of plates is heated at one end and cooled at the other, producing sound at the lowest resonant frequency of the tube. As outlined in Fig. 1, the engine works because the air in the stack of plates is mostly about a thermal penetration depth from the nearest plate, so that the acoustic motion of the air causes it to experience temperature oscillations that are phased with respect to the acoustic pressure oscillations in such a way that net work is done by the air. We call such engines "intrinsically irreversible" because the necessary phasing is caused by the rather poor thermal contact between the plate and the gas a thermal penetration depth away. Not only prime movers but also heat pumps and refrigerators can be designed. The references summarize our current understanding of these phenomena. The agreement between our theoretical work (based on work of N. Rott) and measurements we've made with engines using both air and helium gas thermoacoustic working fluids is good, so we believe we understand these engines well.

Three projects we're currently working on are an acoustic cryocooler, a "beer cooler", and a liquid sodium acoustic prime mover. The acoustic cryocooler, shown in Fig. 2, functions as a refrigerator driven by a modified loudspeaker. A loudspeaker piston P drives the fundamental acoustic resonance in the helium gas in a resonator T-V; heat is thereby pumped from a cold heat exchanger C through a stack of plates S to a hot heat exchanger H. Temperature differences of 100° C and cooling powers of a fraction of a Watt are typical of the results we are getting with this device. The "beer cooler", shown in Fig. 3, is a heat-driven refrigerator designed to absorb heat from a high temperature source, reject heat at room temperature, and thereby remove heat from a load (the beer) just below room temperature. Again, helium gas in a resonator is used; one stack of plates produces sound from heat and another stack uses that sound to refrigerate. The numbers in Fig. 3 are calculated values; this engine is now being assembled.

The liquid sodium acoustic prime mover, the most difficult of our current projects, is shown very schematically in Fig. 4. The thermoacoustic working substance will be liquid sodium instead of a gas. The model engine we are building will have a 1 kHz resonator about a meter long and 10 cm^2 in cross section and should absorb about 5 kW of heat at 700°C , reject about 4 kW at 100°C , and produce about 1 kW of acoustic power. The acoustic power will be converted to electric power either magnetohydrodynamically or by means of a variable reluctance generator (we're experimenting with both) with a high efficiency.

Liquid sodium is an excellent working substance for this kind of engine, for a number of reasons. Its high density (compared to a gas) leads to high power density in the engine. Its low Prandtl number (0.004 at 700°C) makes viscous losses small. Its high electrical conductivity makes magnetohydrodynamic conversion of acoustic power to electric power possible. And its thermal expansion coefficient, while only about a quarter that of a gas, is still adequately large.

We have completed extensive, detailed calculations of the behavior of this engine, and are now assembling components. Although our experience with thermoacoustics in gases has given us confidence in our understanding, our approach, especially toward the liquid sodium engine, is still oriented toward study of fundamental principles rather than optimally engineered designs for specific applications.

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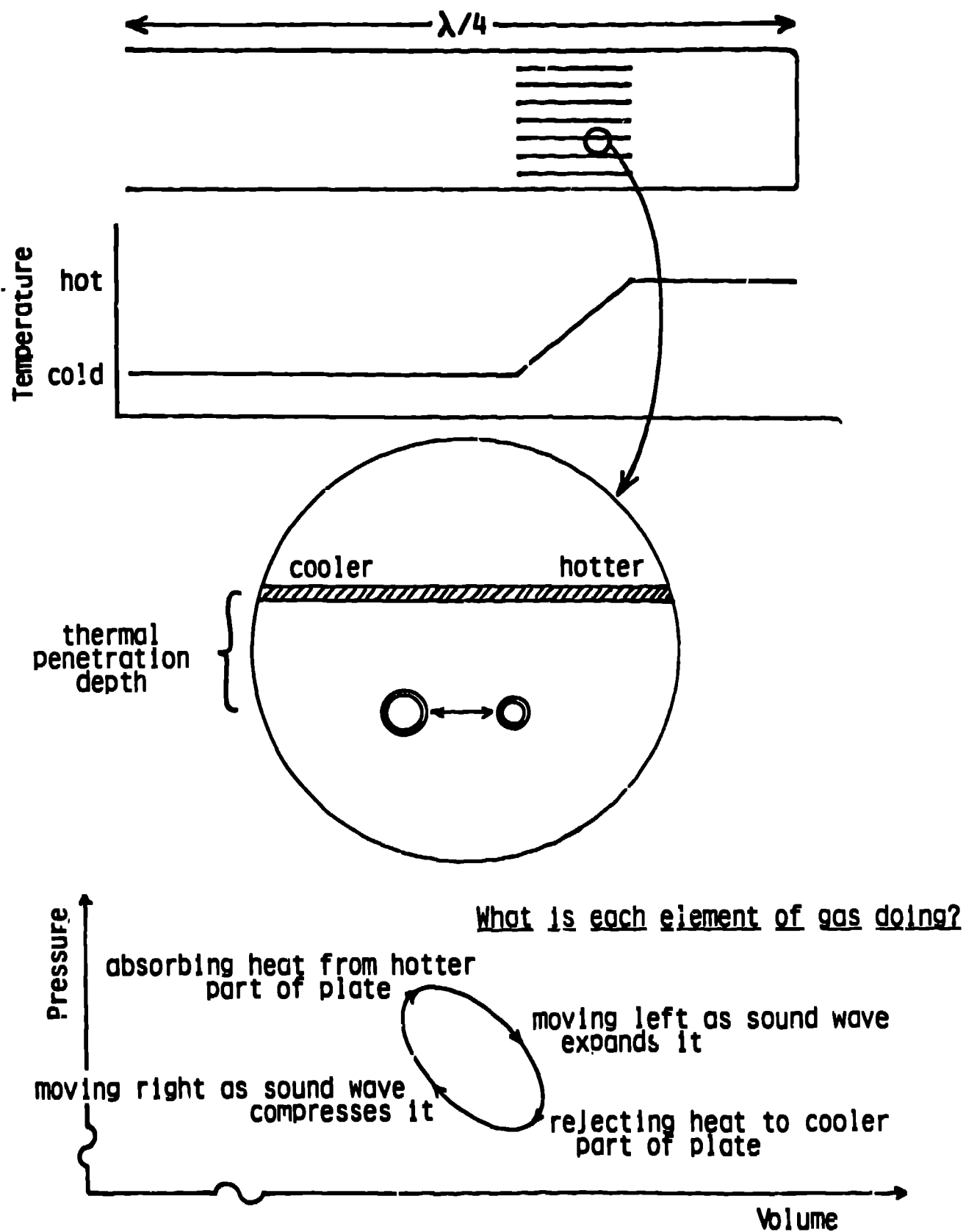


Fig. 1. The demonstration, and how such engines work.

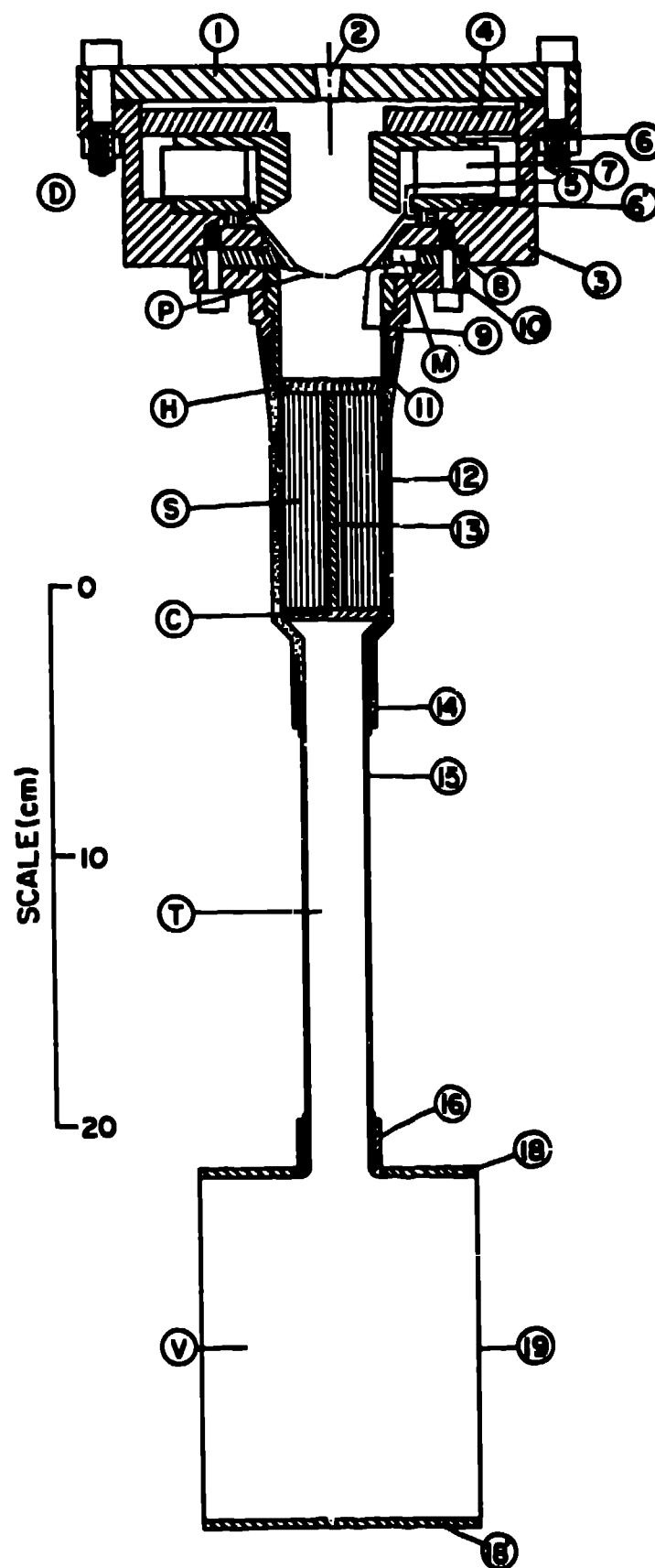


Fig. 2. Acoustic cryocooler.

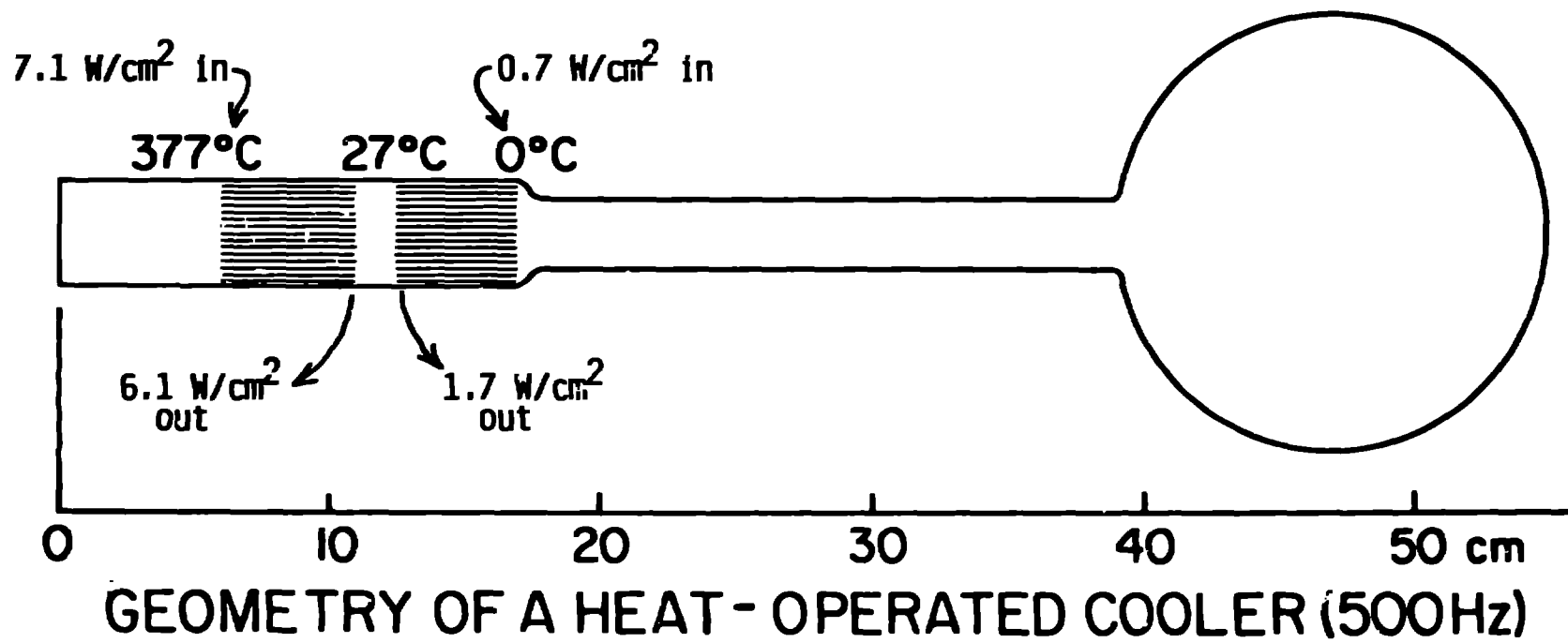


Fig. 3. "Beer cooler" design.

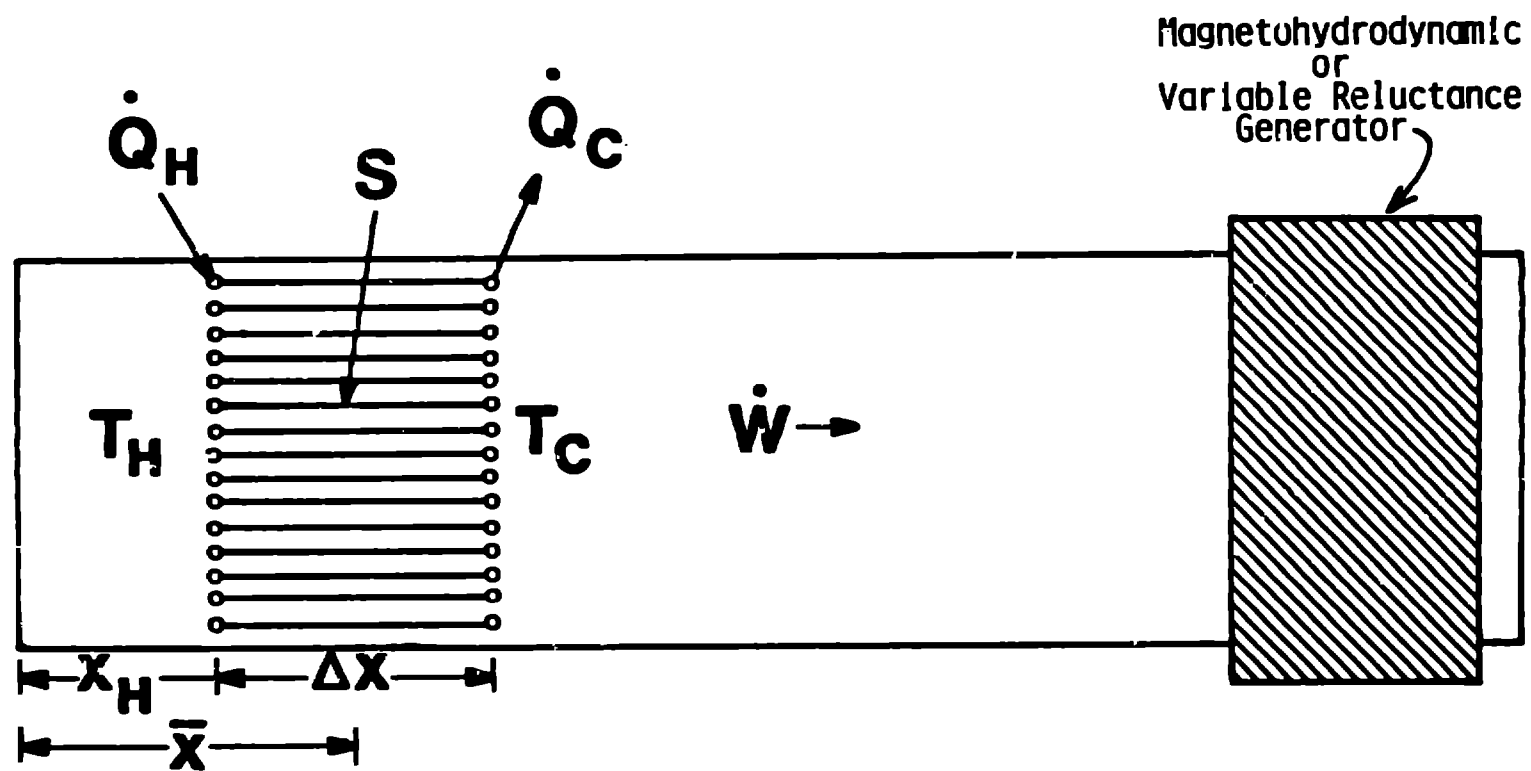


Fig. 4. Schematic, liquid sodium acoustic prime mover.